# Mg II Absorbers: Disks, Halos, Satellites, and Pairs?

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**Abstract.** To understand which parts of galaxies give rise to the variety of observed Mg II absorption profiles seen in QSO spectra, we have embarked upon a program to generate simulated absorption profiles as they would arise from the many typical galactic structures we see today. Here, we present preliminary results for a clumpy, rotating disk which has been sampled by a variety of QSO lines of sight. The resulting ensemble of simulated profiles is qualitatively similar to those observed in HIRES spectra of $0.4 < z < 1.0$ Mg II systems (Churchill, this volume). Additionally, we discuss the statistical contribution from satellite galaxies, which would be expected to contribute additional absorption subcomponents and are likely to have been more numerous at intermediate redshifts. Our preliminary finding is that the common disk and satellite components of galaxies may, to a large degree, be the structures giving rise to a variety of the observed Mg II absorption profiles.

## 1. Introduction

As seen in spectra from HIRES (Vogt et al. 1994) on Keck, the Mg II absorption profiles arising in $0.4 < z < 1.0$ galaxies exhibit a rich variety of subcomponent structure and kinematic complexity (Churchill, Steidel, & Vogt 1996; Churchill, this volume). The key to applying QSO absorption line studies to the problem of galaxy evolution hinges upon establishing the connections between absorption–line properties and the components and processes in galaxies that give rise to the absorption. One simple absorption property is the "morphological or kinematic shape" of the profiles, which we explore here.

The status–quo picture of Mg II absorbers is that absorption arises from "clouds" spatially distributed throughout galactic halos. The covering factor of these clouds is inferred to be nearly unity, since intermediate redshift galaxies that lie within 35–40 kpc of a QSO line of sight rarely fail to exhibit Mg II absorption [Steidel 1995 (S95)]. However, in the present–day Milky Way, only a $14 \pm 8\%$ covering factor is observed for Mg II down to $W_0 \sim 0.05$ Å (Bowen, Blades, & Pettini 1995). The implication is that either halo clouds may not be

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the *primary* source of Mg II absorption or that the spatial distribution of halo gas has evolved substantially from $z \sim 0.4$ to the present.

We are exploring the theme: "what you see is what you get". In other words, we examine the hypothesis that the galactic substructures known from local galaxies are sufficient to give rise to the observed variety of Mg II absorption profile morphologies. Our first goal is to ascertain if models based upon this hypothesis fail to produce simulated profiles similar to those observed. The two components *known* to exist in local galaxies that we explore here are:

1. Extended and warped H I disks of spiral/disk galaxies,
2. Dwarf satellite galaxies associated with typical $L^*$ galaxies.

Mg II is associated with H I down to a neutral column density $N_H \sim 10^{17}$ cm$^{-2}$, so one issue is how extended these disks are to this H I column density. Likewise, we need to estimate the gaseous extent of dwarf satellite galaxies and the number of dwarfs that are associated with a typical $L^*$ galaxy. We have assumed that no dramatic evolution in the spatial distribution of these absorbing structures has occurred from $z \sim 0.4$ to the present and have preliminarily explored whether these present–day and familiar components can qualitatively reproduce the morphological shapes and variety of observed Mg II absorption profiles.

## 2. Contribution to Mg II Absorption From Galaxy Disks

Naively, one would at first expect that highly inclined disk galaxies, observed over the full range of impact parameters, would not frequently give rise to Mg II absorption. However, when we account for the increased pathlength and velocity dispersion sampled through an inclined disk, we find that "clumpy disk" models yield nearly the same absorption properties as do models of "clouds" distributed in a spherical halo [Charlton & Churchill 1996 (CC96)]. Both models yield an effective covering factor of $\sim$ 80%, and so are in apparent conflict with the very small number of non–absorbing galaxies (only 3/51) reported to lie below the $D = 38h^{-1}(L_K/L_K^*)^{0.15}$ kpc "absorption boundary" (S95). However, the survey work of Steidel, Dickinson, & Persson (1994) reported in S95 is not fully complete. Once their observational selection procedures to date are considered, and the possibility of an occasional absorber misidentification is accounted for, the discrepancy in covering factor between our models and the data may be resolved (CC96). Thus, both spherical or disk models are currently consistent with the available data. We have developed simple tests useful for distinguishing between these two geometries. These tests rely upon high–spatial resolution imaging of the galaxies and high–resolution spectra of the absorption (CC96).

We now address "what you get" in Mg II absorption when you sample lines of sight through a galaxy disk of various orientations. We designed a Monte Carlo clumpy disk with empirical properties roughly consistent with those seen in nearby spiral galaxies. We randomly distributed "absorbing clouds" in a disk, which we have assumed to be increasing in thickness from 1 kpc to 10 kpc and to have a truncation radius of 50 kpc. The individual clouds have radii of 1 kpc and number densities given by $n_{cl} \sim 1/R$ (so that the equivalent width $W \sim 1/R$). The cloud–cloud velocity dispersions were $\sim$ 6 km s$^{-1}$. These

models were viewed from random orientations at a given impact parameter, and the resulting absorption profiles were sampled every 2 km s$^{-1}$. The profiles were then convolved with the HIRES instrumental profile, and Poisson noise was added to give a $S/N \sim 30$. In Figure 1, we show a series of simulated Mg II profiles with increasing impact parameter, which allows qualitative comparison with observed HIRES spectra (Fig. 1 of Churchill, this volume).

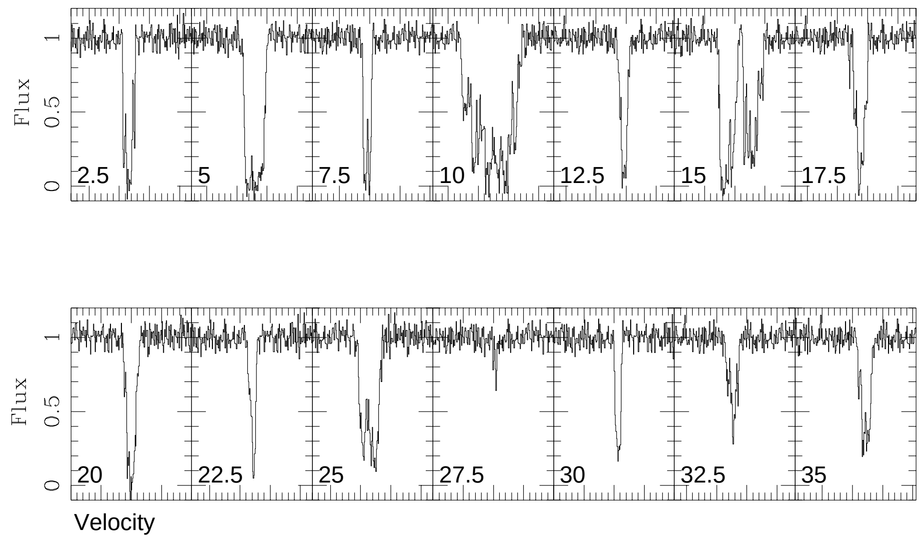


Figure 1. Simulated Mg II absorption profiles obtained by viewing a clumpy, rotating disk at random orientations. The impact parameter is increased in increments of 2.5 kpc through the series. Each panel has a velocity spread of 400 km s$^{-1}$.

We have also found that a series of model disks viewed with increasing inclination (at fixed impact parameter) show an increasing spread in subcomponent velocity and a gradual progression toward greater kinematic complexity (i.e. blended components separate in velocity space). Thus, simulations such as those presented here will yield an orientation test, once high–spatial resolution images of the absorbing galaxies are available.

## 3. Contribution to Mg II Absorption From Satellite Galaxies

A major qualitative difference between the simulated absorption spectra from the clumpy disk models and the observed profiles is the presence of "high–velocity" weak features in the observed data. We consider the probability that lines of sight through $L^*$ galaxies may also pass through dwarf satellites, which would give rise to outlying and relatively weak lines. Assuming that the gaseous cross section of a satellite is given by $R_{sat} = 35(L/L_{B*})^{0.2}$ kpc, we computed the mean number of satellites intercepted by random lines of sight at various impact parameters through a Milky–Way like galaxy in a "Local Group" (using the actual distances and luminosities of Local Group members). The overall

probability of intercepting a satellite ranges from 0.2 to 0.35, with the dominant contribution being LMC and SMC–like satellites.

How many satellites would be needed to produce a unity probability of interception? Assuming that the luminosity distribution of dwarf satellites can be described by a Schechter function with $\alpha = -1$ ($-18.5 < M_B < -12.5$), and that they follow an isothermal spatial distribution between $0 < R < 400$ kpc around the primary, we find that that $\sim 20$ satellites are required. There are roughly 4–5 dwarf satellites associated with the Milky Way that fit these specifications. Thus, evolution in the numbers of dwarf galaxies associated with $L^*$ galaxies would be required if these "high–velocity" weak features do arise from dwarf satellites. If we extrapolate the results of Carlberg, Pritchett, & Infante (1995) that the number of close pairs increases with redshift as $(1+z)^{3.4}$, we find 25–30 satellites would be expected per Milky Way by $z = 0.7$. If so, an even larger number of "high–velocity" Mg II absorption lines would be predicted from $z > 1$ galaxies.

## 4. Is What You See What You Get?

A simple preliminary clumpy disk model appears to produce simulated Mg II profiles remarkably similar to those observed from $0.4 < z < 1.0$ galaxies. Combined with a plausible contribution from satellite galaxies, we might find that these simulated profiles would also exhibit the higher–velocity weaker features commonly observed. We strongly caution, however, that this preliminary model is far from unique. Our future efforts will include modeling distributions of clouds in a spherical geometry with various velocity fields (eg., rotation, radial infall, and isotropic). If the simulated spectra from familiar local galactic structures and systematic velocity fields match the "morphological" and kinematic substructures of observed profiles, then there may not be so much more behind producing Mg II absorption than what meets the eye. It would be fruitful to observationally confirm if higher–velocity weaker features are actually produced by satellite galaxies and to establish if the orientation effects expected from disks are seen. Such a study would depend upon deep high–spatial resolution images (roughly 20–30) of the galaxies for which HIRES spectra are available.

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## References

Bowen, D.V., Blades, J.C., and Pettini, M. 1995, ApJ, 448, 662

Carlberg, R. G., Pritchett, C. J., and Infante, L. 1995, ApJ, 435, 540

Charlton, J.C., and Churchill, C.W. 1996, ApJ, 465, in press (CC96)

Churchill, C.W., Steidel, C.C., and Vogt, S.S. 1996, ApJ, submitted

Steidel, C.C. 1995, in Quasar Absorption Lines, G. Meylan, Garching: Springer–Verlag, 139 (S95)

Steidel, C.C., Dickinson, M., and Persson, S.E. 1994, ApJL, L75

Vogt, S.S. et al. 1994, SPIE, 2198, 326